RED FLAG FIRE ALERT:
PREVENTION EVALUATION UNDER RISK*

by
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A probability model for evaluating the effectiveness of fire prevention efforts that are limited to application during unique weather situations as described by the National Fire Weather Services Red Flag (severe fire danger) emergency fire weather forecast system has been developed. Methods for estimating the "unimproved" fire situation are described. Expected monetary savings in suppression cost serves as the evaluation criterion. Analysis of the model indicates a predominate affect of the conditional probability of fire size at suppression on the evaluation criterion.

*Risk is used in the technical meaning associated with decision theory and not as normally used in professional fire literature.

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Major loss of life, property, and natural resources occur almost every fall in southern California from wildland fires fanned by Santa Ana winds blowing hot and dry off the deserts often at speeds exceeding 50 MPH. To prevent the ignition of these fires a Red Flag Fire Alert program has been developed and implemented in pre-selected high hazard areas which are extremely vulnerable to major conflagrations. A posterior evaluation of the effectiveness of the 1975 program on the San Bernardino Ranger Unit, Division of Forestry, State of California shows an expected monetary savings of $26,527 in suppression costs.

In 1973 the California Division of Forestry (CDF) began a program to prevent conflagrations from occurring during periods of Santa Ana winds, the program is called the Red Flag Fire Alert. The name Red Flag being derived from the National Fire Weather Services (NFWS) Red Flag (severe fire danger) emergency fire weather forecast system. The first two stages of a Red Flag Fire Alert are based on the NFWS predictions of Red Flag Watch (given 72 hours in advance of weather change) and Red Flag Warning (given 12 hours in advance of fire weather change). Stages III and IV are discretionary and called by the individual fire managers in the field, Stage III, the action plan, is implemented when critical changes in the fire weather actually occur and Stage IV cancellation is implemented immediately after the most critical portion of the fire weather has past.

The Red Flag Fire Alert program combines the efforts of local fire organizations, volunteers from organized citizen band radio groups, law enforcement, public utilities, and paid CDF firefighters, along with mass media saturation to increase the publics' awareness of the critical fire weather and urging their support in preventing fires.

Similar programs are conducted by the Los Angeles County Fire Department (since 1963) the Santa Barbara County Fire Department (since 1971) and the Ventura County Fire Department (since 1975). All fire departments and the CDF operate their programs in cooperation with the United States Forest Service (Cleveland, Angeles, Los Padres, and San Bernardino National Forests).

During the calendar year of 1975 the Red Flag Fire Alert was activated within the areas of CDF Region VI fire protection responsibility 21 times, as compared to six times in 1973 and three times in 1974. The San Bernardino Ranger Unit which has been evaluated, implemented the Red Flag Fire Alert 15 times ranging from having three patrols out on October 23, 1975 to 35 patrols on November 24, 1975 and one aircraft spotter.

The evaluation of prevention effectiveness requires knowledge of what the fire situation would have been without the added prevention effort. A method is required that is cognizant of the indefiniteness associated with the "unimproved" fire situation. Probability statements treat such ambiguous situations best. Models were developed from historical fire records which estimate the probabilities of man-caused fire occurrence and fire suppression size for the Unit. Combining these probabilities with fire suppression costs per acre provides an expected cost for the unimproved situation. Proportional allotment separates the costs due to variations in prevention coverage during the alerts. Finally, comparison of actual fire suppression costs with predicted unimproved cost provides an estimate of the value of the Red Flag Fire Alert Program.

This paper reports on an exploratory effort to: (1) adopt quantitative analysis techniques used in business decisions to evaluation of the effectiveness of the Red Flag Fire Alert program, and (2) develop rudimentary models for developing the information needed by the above process.

All evaluation processes have the same essential characteristics. This requires: (1) the establishment of criterion to be used, (2) determination of the model which will be used and the values of the variables of the process, and (3) determination of the effectiveness consistent with the established criterion.

CRITERION

Decision theory recognizes three states of knowledge:

(1) Certainty--the situation where one can specify exactly what will happen during the evaluation period;

(2) Risk--used to describe a situation where one can specify the probability of all possible outcomes; and

(3) Uncertainty--refers to a condition where one can not specify the probability distribution of the outcomes.

Prevention may never be able to be evaluated under conditions of certainty. However, the codification of historical fire records and subjective human knowledge can provide estimates of probability measurements suitable for evaluation under risk conditions. Most real world evaluations are also performed in this type of situation. An appropriate criterion under conditions of risk is the expected monetary value (EMV).[1/] This concept will be described and illustrated later.

M O D E L

The establishment of EMV criterion by definition determines the model for evaluation. The model consists of two major parts (1) formulation of the expected fire situation, and (2) establishment of expected suppression costs and fire damages.

Expected Fire Situation

In order to arrive at the expected fire situation for the San Bernardino Ranger Unit two probability distributions are needed. First the probability of 0, 1, 2,...,n man-caused fires starting on a Red Flag Fire Alert day is needed. In addition, given a fire has started on the above day, what is the probability that the fire will be greater than or equal to 100 acres (a large fire) when it is suppressed? This second estimate is referred to as a conditional probability--it's conditional on a fire starting in the Unit.

The expected large fire situation can now be determined by multiplying the arithmetic average number of man-caused fires by the conditional probability of a large fire for that day. In a similar manner the expected small fire situation can be determined. The sum of the two expected events provide the estimate of the fire situation for the Unit on the Red Flag Fire Alert Day.

Expected Suppression Cost and Fire Damages

The expected suppression cost per acre can be determined from historical fire records adjusted for inflation. A broad analysis of the California Division of Forestry fire records indicates that for small fires the cost

per acre is $180.64. For larger fires the cost per acre is a function of the number of acres burned (Figure 1).[2/]

Many different fire damage appraisal systems are used by fire organizations.[3/] Comparison of estimated damage to timber resources alone by two such systems differ by 636 percent.[4/] Due to the questionable validity of available damage appraisal systems, this evaluation was restricted to expected savings in suppression costs alone. Adjustments due to added prevention cost can be made if valid cost records are available. However, the total prevention costs both direct and indirect are generally difficult to identify under most existing budgeting and accounting systems.[3/]

Several probability estimates are required to use the above EMV model. Methods for estimating these variables are needed.

Probability of Man-Caused Fire Occurrence

Extensive research on the development of a nationally applicable system for predicting the number of man-caused fires to be expected on a unit of wildland is being developed as part of the National Fire Danger Rating System.[3/]

At a minimum, such probabilities should be a function of the day's place within the local fire season, the actual day within the week, long range fire occurrence trends, and weather conditions. An empirical estimate of such a measurement was developed for the Unit. The Red Flag Fire Alert program was initially used by this Unit in 1974. Therefore, the fire occurrence records for 1969 to 1973 (5 years) was used to estimate the unimproved fire situation. The number of man-caused fires [Δ] per Julian date (J) per year was fit by a smooth curve using periodic regression.[5/]

$$\Delta_J = [1.207 - 0.491\cos\gamma - 0.255\sin\gamma + 0.126\cos 2\gamma + 0.026\sin 2\gamma - 0.026\cos 3\gamma + 0.031\sin 3\gamma + 0.048\cos 4\gamma - 0.027\sin 4\gamma]$$

according to potential fire hazard and which detect and measure changes in fuel build-up and potential fire hazard, including naturally occurring fuels and fuels added by man's activities in the wildland.

Plans for an emergency prevention system should include expansion of the total mobility concept to wildfire prevention. It should be possible to move selected prevention specialists to potentially dangerous areas as the fire threat builds. Emergency prevention systems may be made up of alternative plans for acceleration of fire safety warning efforts, law enforcement, including closures and selective fuel hazard reduction.

RESEARCH AND DEVELOPMENT

When reporting on prevention research and development needs, the Task Force reported that there has never been an unbiased, comprehensive and indepth analysis of the wildfire problem in the United States aimed specifically at identifying research needs. The orderly planning execution, and funding of research programs has suffered from the lack of a problem analysis, and the Task Force recommended that this job be done.

The Task Force recommended that the Firest Service should retain overall responsibility for wildfire prevention research and development in the United States.

INCREASED EMPHASIS ON WILDFIRE PREVENTION

In the final chapter of the report the Task Force reiterated their conclusion that wildfire prevention requires greater emphasis nationwide.

Where $\gamma = 0.017(J-1)$. The standard deviation (SD) of this equation was 1.4785. This equation is now used as a "base line" description of the average man-caused fire occurrence for the Unit.

Analysis of the residuals (difference between the predicted values and the observed values) would show a systematic bias. For this analysis it it assumed that the bias is due to weather conditions and fluctuations associated with the different days of the week. The Los Angeles Office of the National Weather Service, U.S. Commerce Department provided past records that identified Santa Ana days up to 1971 for this area. Each residual for each Santa Ana day was transformed into a standard measurement (z).[6/]

$$z = \text{Residual/SD}$$

Each z was then stratified as to its day of the week. The average value (M) and standard deviation (σ) for each stratum was determined (Table 1).

An estimate of the expected number of man-caused fires $E(\Delta_{SA})$ during Santa Ana days for this Unit is now possible. The periodic regression equation provides an average unadjusted value for any day within the fire season. The mean (M) of the appropriate stratum can be added to arrive at an adjusted measurement due to weather conditions (Santa Ana) and the fluctuation between the different days of the week.

One additional adjustment is desirable to account for long term fire occurrence trends. The average number of man-caused fires (on a Santa Ana day) was determined for the 1955 to 1970 period.[7/] A linear regression of this data shows that the number of fires is increasing by 0.055 each year.

$$E(\Delta_{SA/YR}) = 0.055(\text{Year}) - 2.551$$

The F-value (9.56), a method to evaluate the "fit" of the equation to the data, is significant at the 99% level. The standard error of the regression coefficient (0.055) is 0.0179. Assuming that the periodic regression equation best represents the mid year (1971) of the period analyzed, an adjustment due to long term trend of 0.2217 should be made for 1975. Therefore, the expected number of mancaused fires for the Unit is given by:

$$E(\Delta_J) = \Delta_J + M + 0.2217$$

where Δ_J and M are determined using the appropriate 1975 Santa Ana dates.

Assuming that the actual man-caused fire occurrence for the Unit on a given day is normally distributed about the expected number of fires, the standard deviation of the stratum (σ) can be used to estimate the probability of 0, 1, 2, ..., n man-caused fires occurring. An estimate for the November 25, 1975 is provided in Table 2.

Unfortunately, the expected number of fires is insufficient information for the EMV model, or for that matter, fire management resource alert planning. An additional model that estimates the conditional probability that a fire starting on the "given" date will be large when it is suppressed is also needed.

Conditional Probability of Fire Size

No refined model for estimating the probability that a fire will be larger than 100 acres when it is suppressed, given a fire suppression organization, fuels, weather conditions, etc. exist to date. FOCUS [8/] could be manipulated in a manner that could provide a realistic evaluation. However, as currently used it does not provide such information. If a large set of fire events (selected for the desired Santa Ana weather conditions) were pitted against the FOCUS Suppression Module, an estimate

Day	Mean (M)	Standard Deviation	No. of Observations
Monday	0.4942	1.1067	19
Tuesday	0.1286	0.6493	22
Wednesday	0.1333	0.6206	22
Thursday	-0.0276	1.1476	22
Friday	-0.0177	0.6774	26
Saturday	0.4901	0.9940	24
Sunday	0.7040	1.1355	20

Table 1. Residual statistics for the different Santa Ana days of the week.

of the probability of a large fire could be developed.

Assuming that the past performance of the suppression organization is a good estimate of their future performance, historical fire records can be used to develop an empirical model of this probability. An unpolished model for the San Bernardino Ranger Unit was developed using stepwize discriminate analysis.[9/] This concept was used to examine the month, fuel type, temperature, humidity, fuel moisture, wind direction, and wind velocity for their ability to separate past fires into a group suppressed at less than 100 acres and a group greater than or equal to 100 acres. This technique generates for each fire the a posterior probability for each group, given the set of predictors for that fire, and the a priori probability for the group. Then the group having the highest a posterior probability is selected. Two variables, wind velocity (wv) and temperature (t) showed predictor ability. The posterior probability equation for small fire is:

$$P(\Omega) = \frac{e^{-17.149 + 0.302wv + 0.404t}}{e^{-17.149 + 0.302wv + 0.404t} + e^{-25.373 + 0.420wv + 0.461t}}$$

and the posterior probability of a large fire is: $P(\Phi) = 1 - P(\Omega)$

No tests were run to determine the normality of the predictors. Therefore, the probability statements about significance of the observed F-values should be regarded as approximate (Table 3).

Analysis of the posterior probabilities shows that 95.3 percent of all small fires and 35.7 percent of all large fires were classified correctly. A deeper examination of the misclassified fires (19 out of 225) indicates that only four actual small fires had a high probability of being a large fire (Table 4). And that all nine of the misclassified large fires had high probabilities of being a small fire. It would appear from this that

Event: I = 1,2,3,...,6 (No. of Fires)	Probability of Event
0	0.1290
1	0.2810
2	0.3405
3	0.1924
4	0.0506
5	0.0062
6	0.0003

Table 2. Estimate of the probability for 0 to 6 fire occurrences on November 25, 1975 for the San Bernardino Ranger Unit.

Predictor	Actual F-Statistic	F-Test Level
Wind velocity	13.945	$F_{.999}(1,223) < 11.33$
Temperature	7.672	$F_{.999}(2,222) < 7.32$

Table 3. Predictors used in the discriminant analysis. The degrees of freedom for the critical F-value are shown in parentheses. Each predictor indicates significance of at least 99.9% level.

"unusual" suppression efforts could be associated with many of the misclassifications.

Assuming that the source of misclassification is essentially independent of posterior probabilities, adjustments due to errors in classification are possible. Thus, 64.3 percent of fires classified as large are in fact a small fire. In a similar fashion, 4.4 percent of fires classified as small are in fact large fires. Hence, the adjusted conditional probability of a small fire is: $P(\Omega_c) = P(\Omega) \times 0.953 + P(\Phi) \times 0.643$ and the adjusted conditional probability for a large fire is: $P(\Phi_c) = 1 - P(\Omega_c)$. Therefore, an equation is available for the estimation of the probability that a man-caused fire will be greater than or equal to 100 acres for the actual Santa Ana weather conditions and the Units fire resources.

Sundry Requirements

The EMV model requires several additional items of information for application. First, the average acres burned within the Unit for small and large fires are required. Historical fire records can be used to collect this data. Second, knowledge of actual acres burned during the Red Flag Fire Alert for both fire categories is needed. Finally, a measurement of the proportion of the risk associated with the alert area to the Unit's risk is essential. Currently, subjective probability--an estimation of this proportion by knowledgeable personnel within the Unit--is being used. A more meaningful appraisal of the risk within the alert area can be developed by the use of spatial risk.[10/] This provides a relative measurement of the risk associated with specific areas of the Unit. With the above information it is now possible to evaluate the effectiveness of "unusual" prevention efforts by the use of the EMV model.

True State	No. of Cases Misclassified	Posterior Probability	
		Small Fire	Large Fire
Small Fire	3	0.10 - 0.19	0.81 - 0.90
Small Fire	1	0.20 - 0.29	0.71 - 0.80
Small Fire	6	0.40 - 0.49	0.51 - 0.60
Large Fire	2	0.90 - 1.00	0.00 - 0.10
Large Fire	4	0.80 - 0.89	0.11 - 0.20
Large Fire	3	0.70 - 0.79	0.21 - 0.30

Table 4. Posterior probabilities of misclassified fires on the San Bernardino Ranger Unit.

I L L U S T R A T I O N

Winds of 21 MPH existed within the San Bernardino Ranger Unit on Tuesday, November 25, 1975. A Red Flag Fire Alert was implemented on an estimated sixty-five percent of their area. Eleven California Division of Forestry, ten REACT, three Southern California Edison Co. patrcls and one aircraft were used to complement the normal efforts. One spot fire was detected within the patrol area during the alert.

Initially, an estimate of what the unimproved condition would be is calculated (Table 2). Tuesday being a relatively light fire day within this Unit, there was about one chance in ten of zero fires. However, the odds of one or two fires is high. The average fire occurrence (P=0.5) is 1.31 fires for the day.

As it turns out for this Unit on this day, the conditional probability of any fire occurring within their area being greater than or equal to 100 acres is also low (Table 5). Given the existing weather conditions and the Unit's past suppression history associated with the weather, there is approximately one chance in eight of the fire getting to be large.

The potential of these two probabilities as planning/forecasting tools is obvious from examination of other 1975 alert days. For instance, on the 27 of September the expected fire occurrence was 2.3 fires (high) with a conditional probability of a large fire size of 0.0888. However, on the 24 of November the expected number of fires was 1.75 and a conditional probability of 0.3120 (very high). Perhaps the planned initial attack should be increased on days having a high conditional probability.

The expected suppression cost for small and large fires within the Unit can now be determined (Table 6). Due to the general similarity of the calculations for small and large fires, only the small fire situation will be followed herein. The expected number of fires (1.31) is multiplied by the conditional probability of a small fire (P=0.878) to arrive at the expected number of small fires (1.1506). Multiplication of this number by the average number of acres burned for small fires (1.9629) provides the expected acres burned by small fires (2.259). By multiplying this figure by the average suppression cost per acre on small fires ($180.64) provides the expected cost ($407.58) for small fires on this Unit. Combining this value with the expected suppression cost ($5,393.84) for large fires gives the total expected suppression cost ($5,801.82). Finally, this value is multiplied by the subjective probability of the proportion of the Unit's risk associated with the alert area (P=0.65) to arrive at the expected suppression cost in the patrol area (A = $3,771.18).

The actual suppression cost within the alert area is calculated for both small and large fires. Since there was one spot fire (assume 0.25 acres) this actual suppression cost was $45.16 (Table 7). A comparison of actual with expected suppression cost provides the expected monetary value (EMV) of the prevention effort. On this date the "estimated gain" due to prevention was $3,726.

The use of the word "estimated gain" is deliberate in order to emphasize that the EMV is a probability measurement. This concept is similar to a statement that tomorrow will probably be a rainy day. Such a statement is clear and understandable, whether you agree with it or not. More specifically,

Event: Y(I) (Fire Size)	P(Y(I)) Probability of Event
Y(1) = A, B, or C	0.6880
Y(2) = D or greater	0.3120

Table 5. Conditional probability of a fire being small or large when suppressed, given there was a fire on the San Bernardino Ranger Unit on 25 November 1975.

EXPECTED SUPPRESSION COST FOR A, B, OR C FIRES ON 25 NOVEMBER 1975

EXPECTED FIRE OCCURRENCE:		CONDITIONAL PROBABILITY		EXPECTED NO. OF A, B, OR C FIRES		AVERAGE NO. OF ACRES BURNED, GIVEN A-C FIRE		EXPECTED ACRES BURNED BY A-C FIRES		AVERAGE SUPPRESSION COST PER ACRE		EXPECTED COST
1.31	X	0.878	=	1.1506	X	1.9629	=	2.259	X	$180.64	=	$407.98

EXPECT SUPPRESSION COST FOR D OR GREATER FIRES ON 25 NOVEMBER 1975

EXPECTED FIRE OCCURRENCE:		CONDITIONAL PROBABILITY		EXPECTED NO. OF D OR LARGER FIRES		AVERAGE NO. OF ACRES BURNED, GIVEN A LARGE FIRE		EXPECTED ACRES BURNED BY LARGE FIRE		AVERAGE SUPPRESSION COST PER ACRE		EXPECTED SUPPRESSION COST
1.31	X	0.122	=	0.1599	X	487.5625	=	77.952	X	$69.19	=	$5,393.48

TOTAL EXPECTED SUPPRESSION COST FOR 24 NOVEMBER 1975 = $5,801.82

EXPECTED SUPPRESSION COST FOR RED FLAG PATROL AREA FOR 25 NOVEMBER 1975

TOTAL SUPPRESSION COST		PROB. OF FIRE WITHIN PATROL AREA		EXPECTED SUPPRESSION COST IN PATROL AREA
$5,801.82	X	0.6500	=	$3,771.18

Table 6. Illustration of the determination of the expected suppression cost for the Red Flag Fire Alert area in the San Bernardino Ranger Unit on 25 November 1975.

ACTUAL SUPPRESSION COST IN RED FLAG PATROL AREA FOR 25 NOVEMBER 1975

NO. OF ACTUAL ACRES BURNED (A-C FIRES)		AVERAGE SUPPRESSION COST		COST OF A-C FIRES	* * *	NO. OF ACTUAL ACRES BURNED (LARGE FIRES)		EXPECTED SUPPRESSION COST		COST OF LARGE FIRES
0.25	x	$180.64	=	$45.16	*	0.0	x	$0.00	=	$ 0.

Table 7. Development of the actual suppression costs for the Red Flag Fire Alert Patrol area in the San Bernardino Ranger Unit on 25 November 1975.

Variable	% Change in Output
Expected Fire Occurrence	7.1
Probability of Fire Size	55.2
Average Acres Burned:	
Small Fire	0.7
Large Fire	6.4
Average Suppression $/Acre:	
Small Fire	0.6
Large Fire	9.4
Probability of Fire Within Patrol Area	10.1

Table 8. Change in the gain on 25 November 1975 due to a 10% change in the value of EMV model variables.

the EMV model states that if you accept the complex fire situation in the Unit as approximately stable--fire occurrence vary over a wide range but with consistent frequency--then the expected gain is a sample of one day from a broad range of possibilities. The sample may be an unfavorable or favorable event. The frequency of occurrence of the samples are, however, governed by the underlying probability distribution. Therefore, each sample can be quite a misrepresentation of the average situation, but a large number of samples should approach a "true" evaluation of the effectiveness of the prevention effort.

SENSITIVITY ANALYSIS

The values of the variables used in the EMV model change from day to day. Different levels of accuracy are associated with each variable. Finally, not every change in the value of a variable will result in "significant" changes in the model's output. Sensitivity analysis has been identified as the most important feature of corporation models.[11/] Such an analysis can provide insights on the relevance of the model and identify variables requiring improved accuracy.

This concept varies the value of each variable a little bit, while holding all other variables constant. The difference in the model's output provides a measurement of the significance of the variable. Each of the EMV variables was tested by the use of a ten percent increase (Table 8). The analysis shows the predominant effect of the conditional probability of the expected fire size at suppression. Two variables, the average number of acres burned in a small fire and the average suppression cost per acre for small fires are unimportant. All other variables have approximately a linear impact--a change of one percent in the variable results

in a one percent change in the output. This suggests that refinement of the conditional probability of fire size needs serious attention by the decision maker and comprehensive refinement by fire researchers.

SUMMARY

An expected monetary value model has been described that can be used to evaluate the effectiveness of fire prevention efforts that are limited to application during unique weather conditions. Expected savings in suppression cost was used as the evaluation criteria. Empirical models were described that can provide estimates of the "unimproved" fire situation. Application of the model to the Red Flag Fire Alert program during 1975 within the San Bernardino Raner Unit, California Division of Forestry, showed a savings of $26,527.

Sensitivity analysis of the variables used in the model showed a predominant effect of the conditional probability of the fire size at suppression. Urgent refinement of the crude model for estimating the variable is suggested for broad confidence in the EMV model.

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